USE OF DISCRETE EVENT SIMULATION FOR MANUFACTURING SYSTEMS TRAINING

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Interactive training simulation, lean manufacturing, discrete event simulation

ABSTRACT

This paper presents the use of the ProcessModel discrete event simulation software to support an interactive lean manufacturing training tool. Specifically, this paper focuses on the use of simulation to teach the concepts of push versus pull manufacturing using the Tube Factory Training Simulation. To support the training, a simulation model was developed in ProcessModel of the Tube Factory Training Simulation. In addition, a spreadsheet was developed to present and compare the results of the simulations.

INTRODUCTION

Lean manufacturing is a systematic approach to identifying and eliminating waste (all non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection (NIST MEP 1998). Competition is forcing manufacturers to improve quality, reduce delivery time and lower cost. The essence of lean is to compress time from the receipt of an order all the way through to payment. The results of compressing time are greater productivity, shorter delivery times, lower costs, improved quality and increased customer satisfaction.

The key to lean manufacturing is to compress time by eliminating waste and thus continually improving the process. Kaizen is a Japanese word for continuous improvement. The NIST MEP has identified the following lean manufacturing tools: workplace organization, standardized work, visuals, plant layout, quality at source, batch reduction, teams, pull/Kanban, point-of-use storage, quick changeover, one piece flow, cellular, and Takt time (NIST, 1998). A number of books have been written describing these tools (Greif, 1991; Imai, 1986; Nakajima, 1988; Ohno, 1988; Shingo, 1983; Shingo, 1986; Shingo, 1989, and Sekine, 1990).

A generally overlooked tool for lean manufacturing is simulation. This paper addresses the use of the ProcessModel (1999) discrete event simulation software to support an interactive manufacturing training tool. To support the training, a simulation model was developed in ProcessModel of the Tube Factory Training Simulator. A spreadsheet was also developed to present and compare the results of the simulation.

TUBE FACTORY TRAINING SIMULATION

In a push system parts are manufactured based on a sales forecast. As a result, parts are pushed through the plant to meet the forecast. Also, work-in-process (WIP) is excessive. In a pull system parts are made based on customer orders. As a result, parts are pulled through the plant replenishing what was consumed and WIP is minimized.

The Tube Factory Training Simulation is a hands-on training simulation of a manufacturing line that assembles fifteen pieces of plastic tubes, elbows, and adapters into the final assembly shown in Figure 1 (UAH, 2000). Team members are assigned to four subassembly processes and two material handling operations. Process sheets are given to each operator with instructions and a drawing of each subassembly.

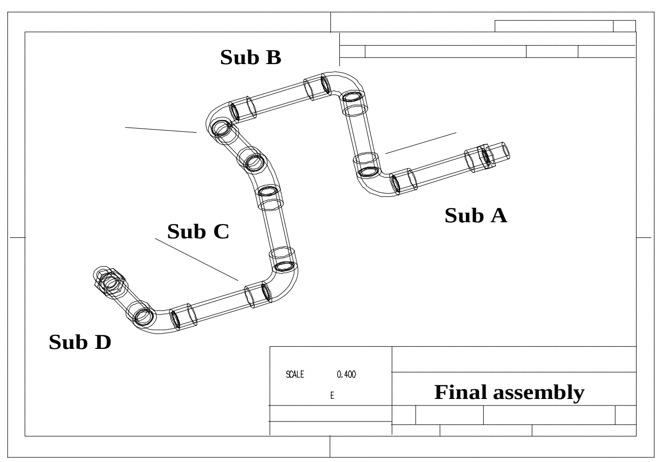

Figure 1. Product of Tube Factory Simulation

The final assembly consists of four subassemblies with the following raw materials:

Sub	Pipe	Elbow	Adapter
A	1	1	1
B	2	2	0
C	2	2	0
D	2	1	1

A layout of the initial Tube Factory Simulation is given in Figure 2. There are separate inventory bins for the pipes, elbows and adapters. The batch layout of the tube factory consists of four subassembly stations and one final assembly station. Material handlers are used to restock the subassemblies with raw material and also to move the subassemblies to final assembly.

The typical rounds of the Tube Factory Simulation are:

- Round 1: Run the tube factory in the batch mode as outlined in Figure 2
- Discuss the concepts of lean manufacturing and make improvements to the line
- Round 2: Run the tube factory given the improvements
- Further discuss lean manufacturing and layout the line for one-piece-flow
- Round 3: Run the tube factory in the pull, or one-piece-flow, mode

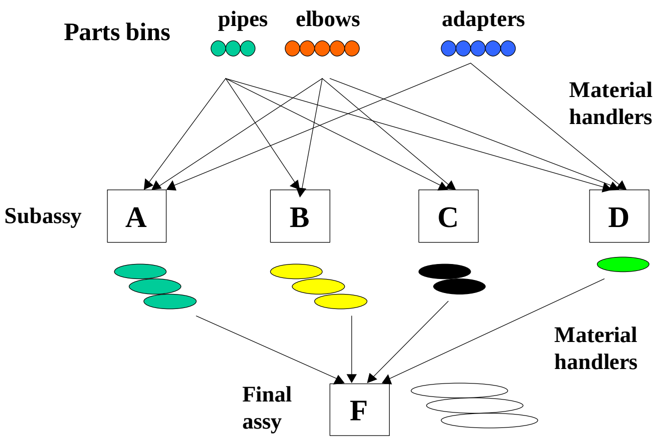

Figure 2. Tube factory layout

For the first round the team is given the task to make as many parts as possible in five minutes. This is equivalent to running the tube factory using the push system. At the end of the first round a brief training session is given on the principles of lean manufacturing. The second round consists of having the team redesign the line based on the principles of lean. The team is given a production goal of 30 parts in five minutes. The simulation is run for another five minutes and the results compared with the first round. A third or fourth round may be necessary to have a one-piece-flow and to meet customer demand.

As previously discussed, some of the basic elements of lean are 1) produce only what is needed, in the quantity needed and when it is needed, 2) practice good housekeeping, 3) eliminate waste, 4) continuously improve the process, or Kaizen, 5) standardize work, 6) one-piece-flow and 7) empower employees.

Standardized work is a set way for an operator to perform a task in order to manufacture consistently high quality parts at low cost. Standardized work requires standardized work instructions, including physical layout of the process, necessary tools and materials, work sequence (steps to make a unit), standard work in process (the smallest WIP to keep the process running, or the largest WIP allowed between two processes), Takt time and cycle time. A typical work sequence for Subassemblies A and B for the tube factory from Round 2 is:

Subassembly A
- Get 2.5 inch pipe
- Get 90 degree elbow and place on end of pipe
- Get male adapter and place on end of pipe
- Place Subassembly A in bin

Subassembly B
- Get 2.5 inch pipe
- Get 90 degree elbow and place on end of pipe
- Get 90 degree elbow and place on end of pipe
- Get 2.5 inch pipe and place into 90 degree elbow
- Place Subassembly B in bin

Takt time is a German word for pace and is the rate at which your customer requires product. Takt time is computed as:

$$\frac{\text{Available time/day}}{\text{Daily demand (parts/day)}}$$

Cycle time is the time for an operator to complete an operation. For the Tube Factory Simulation, the typical cycle time at a subassembly station is approximately 10 seconds. If the available time is 5 minutes (one shift) and customer demand is 30 parts/day, then Takt time is 10 seconds. Therefore, if the cycle times at the subassemblies are 10 seconds or less, the factory can meet customer demand. If not, then ways must be determined to lower the cycle times to 10 seconds. Some of these methods are reallocate some of the work content of an operation to another operators, eliminate waste in the process, improve the methods, or even add more operators or faster equipment.

TRAINING SIMULATION RESULTS

A simple spreadsheet was developed to record the results of each round of the interactive simulation. Figure 3 gives the typical results from a training exercise. The parameters include:

- Shift: 5 minutes
- Labor rate: $9.00/hour
- Fringe: 35%
- Overhead: 100%
- Loaded labor rate = $9.00/hr x 1.35 x 2.00 = $24.30/hour
- Material cost for pipe: $0.04 each
- Material cost for elbow: $0.10 each
- Material cost for adapter: $0.25 each
- Material cost for Subassembly A: $0.39, B: $0.28, C: $0.28 and D: $0.43
- Cost to rework assembly: $0.50
- Selling price: $2.50 each

	Round 1	Round 2	Round 3
Time (Min)	5	5	5
# people Sub Assy A	2	1	1
# people Sub Assy B	2	1	1
# people Sub Assy C	1	1	1
# people Sub Assy D	2	1	1
# people final assy	1	1	1
Material handlers	2	1	0
Inspectors	1	1	0
Total # people	11		5
# shipped goods	1	30	30
# WIP at A	55	5	1
# WIP at B	25	5	1
# WIP at C	25	5	1
# WIP at D	15	5	1
#Finished goods not shipped	4	0	1
Rework	1	3	0
Selling price	$2.50	$2.50	$2.50
Raw materials			
Adapters	5	5	5
Pipe	5	5	5
Elbow	5	5	5
Sales	$2.50	$75.00	$75.00
Material cost			
Shipped goods	$1.38	$41.40	$41.40
WIP	$47.42	$6.90	$2.76
Rework	$0.50	$1.50	$0.00
Raw materials	$1.95	$1.95	$1.95
Loaded labor	$22.28	$14.18	$10.13
Total costs	$73.53	$65.93	$56.24
Profit	($71.03)	$9.08	$18.77

Figure 3. Spreadsheet giving results of rounds

BATCH SIMULATION MODEL

The ProcessModel of the batch simulation of the Tube Factory Simulation consisted of eight entities, nineteen activities, one resource and twenty-six storages. Entities are items being processed, such as parts; activities are tasks performed on entities, such as assembly; resources are agents used to perform activities or move entities, such as a material handler; and storages are waiting areas, or stock places, where entities can wait for further processing.

Rather than show the entire ProcessModel, only two of the more interesting logic elements are presented to demonstrate the use and capabilities of ProcessModel. Figure 4 gives the ProcessModel logic for restocking elbows at Subassembly A. In summary, when the inventory of elbows at Storage INV drops to one, the Resource Material Handler goes to the Storage Elbow BIN, removes ten elbows, and moves then to Storage INV. The move time for the Material Handler is 10 seconds.

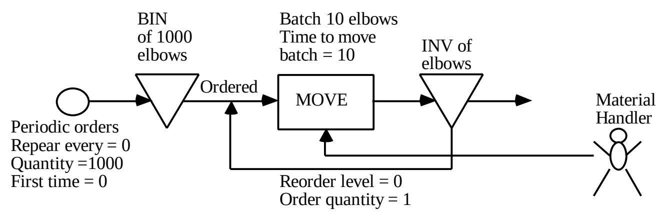

Figure 4. ProcessModel for restock elbows at Subassembly A

Figure 5 gives the ProcessModel logic for assembling one pipe, one elbow and one adapter to make Subassembly A. One part from each of the Storages TUBE_INV, ELBOW_INV and ADAPTER_INV is attached to the order.

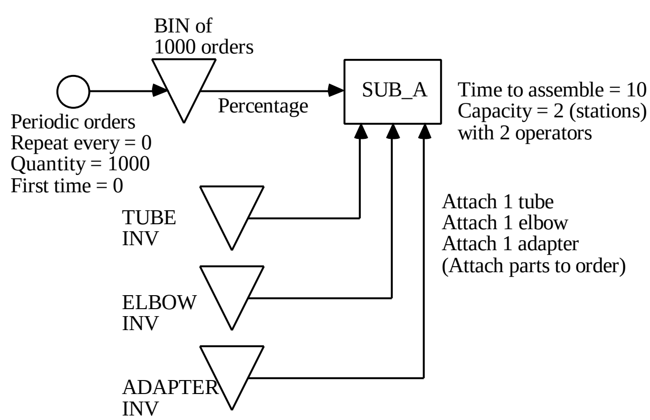

Figure 5. ProcessModel for Subassembly A

ONE-PIECE-FLOW SIMULATION MODEL

Figure 6 is the ProcessModel to simulate one-piece-flow through the Tube Factory Simulation. Note that this model is considerably smaller than the batch simulation model. The ProcessModel has one entity, five activities and two storages. The following assumptions are made:

- Unlimited pipes, elbows and adapters at each subassembly
- One operator fixed at each station (total of five operators)
- Reorder levels of zero when inventory in front of each station drops to zero (i.e., at the beginning of the assembly at each subassembly)
- Reorder quantity of one
- Orders are stacked up at the front of the cell ready to be processed

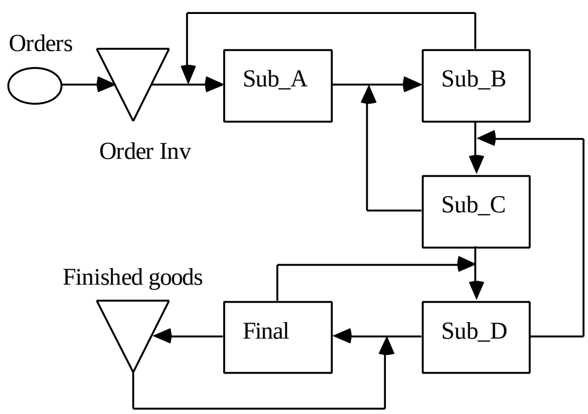

Figure 6. ProcessModel of pull manufacturing for tube factory

The feedbacks loops in Figure 6 are the reorder signals that were discussed in Figure 4. For example, if the WIP at Sub_D (WIP is the same as the inqueue at Sub_D) drops to zero, then a signal is sent to Sub_C to begin the assembly of a subassembly. In ProcessModel the reorder level is set to zero and the order quantity is set to one for each feedback loop. As a result, this logic simulates the pull of parts through the cell. Sub_C will not begin assembly until a signal is sent from Sub_D that its inqueue is zero. Likewise, Sub_B will not begin assembly until a signal is sent from Sub_C that its inqueue is zero. With this logic the WIP in front of each station should never be greater than one. Also, if an activity has not received a signal to assembly a part, the activity will remain idle. On the factory floor WIP is often controlled by the use of Kanban cards.

The simulation model was run for five minutes, or one shift. The service times at the subassembly stations followed the triangular distribution T(8,10,12). The simulation results were:

- Production: 25 (System started empty and idle; therefore the first part was made after 50 sec. Therefore, the theoretical production is 25)
- Maximum WIP in front of each station: 1 (as expected because of the pull logic)
- Subassembly A (also operator) utilization: 92%
- Subassembly B utilization: 89%
- Subassembly C utilization: 86%
- Subassembly D utilization: 82%
- Final assembly: 82%

CONCLUSIONS

In summary, the following conclusions are made:

- Discrete event simulation models combined with training simulations provide a valuable training tool for teaching the concepts of lean manufacturing. The use of training simulations helps the group work better as a team and focus more quickly on identifying problem areas and suggestions for improvement.

- The Tube Factory Simulation provides vivid demonstration to participants of involving and empowering individuals in teams, changing the role of management and helping create a new culture in the workplace.

- The Tube Factory Simulation is particularly effective with new employee orientations and as the initial training for a new Kaizen team whose members have little exposure to lean.

- The use of discrete event simulation models provides the team with a tool to rapidly evaluate various alternatives, such as a new design of the tube factory.

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REFERENCES

Greif, M., 1991: *The Visual Factory*, Productivity Press, Cambridge, MA.

Imai, M., 1986: *Kaizen: The Key to Japanese Competitive Success*, Random House, New York.

Nakajima, S., 1988: *Introduction to Total Productive Maintenance*, Productivity Press, Portland, OR.

NIST, 1998: *Principles of Lean Manufacturing with Live Simulation Users Manual*, NIST Manufacturing Extension Partnership, Gaithersburg, MD.

Ohno, T., 1988: *Toyota Production System*, Productivity Press, Portland, OR.

ProcessModel, 1999: *ProcessModel Users Manual*, ProcessModel Corp., Provo, UT.

Sekine, K., 1990: *One-Piece Flow*, Productivity Press, Portland, OR.

Shingo, S., 1983: Single Minute Exchange of Dies, Productivity Press, Cambridge, MA.

Shingo, S., 1986: *Zero Quality Control: Source Inspection and the Poka Yoke System*, Productivity Press, Portland, OR.

Shingo, S., 1989: *A Study of the Toyota Production System*, Productivity Press, Portland, OR.

UAH, 2000: *Lean Manufacturing Handbook*, University of Alabama in Huntsville, Huntsville, AL.

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